RAPID, COMPREHENSIVE, MISSION ARCHITECTING AT THE JET PROPULSION LABORATORY

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ABSTRACT

One of the first multi-disciplinary optimization challenges a mission concept faces is finding an initial system level architecture that simultaneously satisfies the constraints of cost, the requirements of science, and the capabilities of engineering.

Compounding this challenge, especially in the early formulation of an architecture, is communicating amongst all key stakeholders, in this multidimensional space of constraints and requirements, where the current architecture is not yet adequately defined, or if it is defined, where it is broken.

Recently, a factor of two improvement in the speed of development of the engineering architecture, while also comprehensively considering scientific performance and cost, has been achieved through a single screen visualization dashboard ("S-Chart"), a cost allocation tool, segment level analogy databases and parametric relationships for segment technical capabilities and their technical (Size, Weight, Power, and Data) and financial (Cost) capabilities and/or accommodation requirements.

1. INITIAL FEASIBILITY IN PRE-PHASE A

One of the first multi-disciplinary optimization challenges a mission concept faces is finding an initial system level architecture that simultaneously satisfies the constraints of cost, the requirements of science, and the capabilities of engineering. A mission concept's Pre-Phase A comprises Concept Maturity Levels (CMLs) 1–4 [1].

The CMLs are defined as follows: CML 1 Cocktail Napkin. The science questions have been well articulated, the type of science observations needed for addressing these questions have been proposed, and a rudimentary sketch of the mission concept and high-level objectives have been created. The essence of what makes the idea unique and meaningful has been captured; CML 2 Initial Feasibility. The idea is expanded and questioned on the basis of feasibility, from a science, technical, and programmatic viewpoint. Lower-level objectives have been specified, key performance parameters quantified, and basic calculations have been performed. These calculations, to first order, determine the viability of the concept; CML 3 Trade Space. Exploration has been done around the science objectives and architectural trades between the spacecraft system, ground system, and mission design to explore impacts on and understand the relationship between science return, cost, and risk; CML 4 Point Design. A specific design and cost that returns the desired science has been selected within the trade space and defined down to the level of major subsystems with acceptable margins and reserves. Subsystems trades have been performed.

2. INTERSECTING CONSTRAINTS AND KEY STAKEHOLDERS

The CML 2 Initial Feasibility portion of Pre-Phase-A is performed against the Functional Baseline of Segments within the System [2]. A central challenge during CML 2 is communicating amongst all key stakeholders, in this multidimensional space of constraints and requirements, where the current architecture is not yet adequately defined, or if it is defined, where it is broken. Design thinking functions within a framework of three intersecting "constraints". They are "viability", which is what can economically be done; "desirability", which is what users want or will come to want; and "feasibility", which is what can technically be done [3]. These are typically embodied by the space agency, scientific user, and engineering developer stakeholder communities, respectively. Each stakeholder group focuses on, and often only views, what they want to optimize, and struggles to understand how their decisions affect what the other stakeholder groups view and want to optimize.

However, in the middle of difficulty lies opportunity. For the greatest leverage in system architecting is at the interfaces, and the greatest dangers are also at the interfaces [4].

3. "S-CHART"

Recently, Team-X at the Jet Propulsion Laboratory undertook an effort to improve both the speed and comprehensiveness of initial system level architecting. The method is encapsulated in what can be called an "S-Chart", shown in Figure 1. At the top of the "S-Chart" are the financial constraints allocated amongst the system segments and elements. At the bottom of the "S-Chart" are the scientific performance drivers on the system. The heart of an "S-Chart" is a 4 by 4 Grid where each major column is devoted to a Segment of the System (Launch Segment, Flight Segment Payload, Flight Segment Spacecraft Bus, and Ground Segment). Each major row is devoted to a technical resource within the system (e.g., Size, Weight and Power (SWaP), and Data). Between each column along each resource row in the heart of the "S-Chart" is a cell to

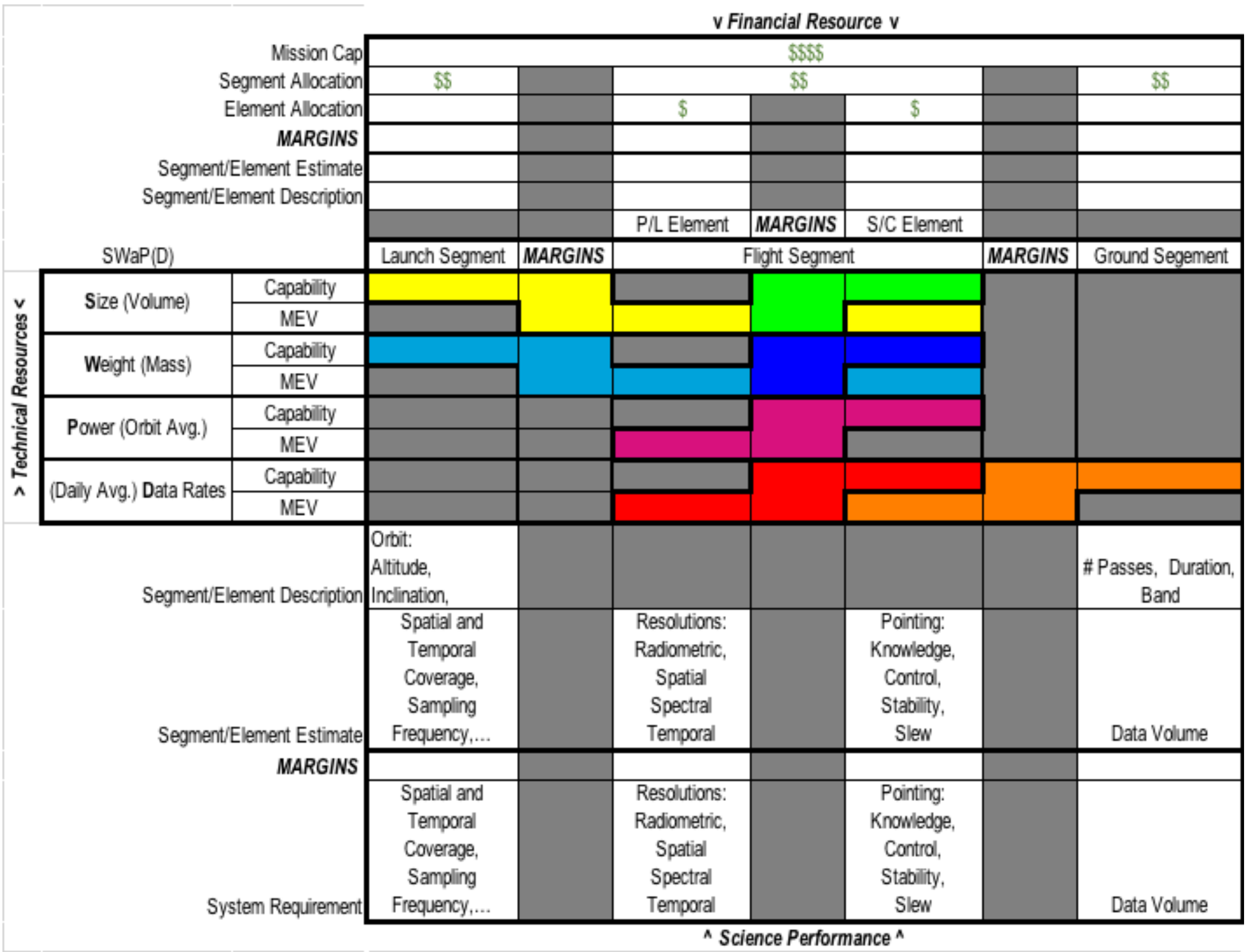

Figure 1. "S-Chart"

note whether or not there is positive technical *Margin* for that resource between the segments. Along the top and bottom of the charts, at the ends of each column, is a space to note whether or not there is positive financial or performance *Margins*, respectively.

There are two sub rows per resource, one for the Maximum Expected Value (MEV) of the resource accommodation requirement of a Segment/Element, and a second row for the Capability of a Segment/Element to accommodate that resource type. The term "S-Chart" comes from the S-shaped comparison that arises between the MEV that needs to be accommodated by one segment, and the capability of another segment to accommodate that resource (e.g., MEV Payload (P/L) Element mass accommodation requirement and Spacecraft (S/C) Element P/L mass Capability).

Various architectural configurations can be quickly entered into the chart, and all stakeholders can immediately see at which interfaces - financial, technical, and/or performance - the system is broken, and adjust either the trial solution for a given segment, or adjust the performance requirements (cost constraints typically being immovable). Incomplete architectures are also readily apparent through empty cells in the "S-Chart".

System architectures have been developed with the "S-Chart" method on time scales of less than 3 hours, a more than factor of two improvement over the typical Team-X mission design study of 6 hours in length.

4. REQUIRED INFRASTRUCTURE

The key enabling information infrastructure necessary to successfully construct an "Initially Feasible" segment level system architecture is the people, tools, and facility. The 6 roles we've found to be absolutely necessary in running a quality architecting session include: a user community representative, a facilitator, subject matter experts for each system segment (Launch Segment, Flight Segment Payload, Flight Segment Spacecraft Bus, and Ground Segment), and a subject matter expert in space system costs. Several tools are also absolutely necessary in running a quality architecting session. In addition to the "S-Chart" itself, one necessary tool is a tool to allocate costs amongst the system segments based on historical actuals. Each system segment subject matter expert requires access to a database of analogies with their associated technical

(Size, Weight, Power, and Data) and financial (Cost) capabilities and/or accommodation requirements. In addition, each system segment subject matter expert requires simple parametric relationships between the technical (Size, Weight, Power, and Data) and financial (Cost) capabilities and/or accommodation requirements for extrapolation from analogue starting points. The facility requirements include a seating arrangement that permits simultaneous viewing of a projection of the S-Chart by all session participants.

5. ACKNOWLEDGEMENTS

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

6. REFERENCES

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